AL17 - An Anode Crisis – The Pitfalls of an Anode Length Increase

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Abstract

The TRIMET Aluminium SE Hamburg smelter changed their anode format in 2017 to reduce the anode current density for future amperage increase. The changes included a new green anode cooling system and a new vibro-compactor to enable production of longer anodes. Further changes in the green anode plant were conducted in the years leading up to the change for the larger anode. The combination of these changes and the raw materials used in the green anode plant had the unfortunate effect that the smelter had an intensive anode crisis resulting in a high green and baked anode scrap ratio in the carbon plant. Furthermore, the anodes produced had a tendency for cracking in the cells. Issues in the electrolysis thermo-chemical system led to high temperature cells. The aluminium output in the electrolysis had to be reduced, as critical cells were cut out of operations and the current was reduced. The findings and the decisions to get back on track are presented in this paper. Additional findings from the literature will put the observations into context with published research.

Keywords: Aluminium electrolysis, Anode crisis, Cracked anodes, Green anode density, Thermo-chemical balance in aluminium electrolysis cells.

1. Introduction

Increasing the capacity of a smelter can be obtained in two ways: expansion or amperage increase. While the first has the potential to increase the capacity in a big step, it has needs in capital investment (between 3300 and 5700 US$ per annual ton [1-3], governmental permits and area available. The second has the potential for plants, especially for ones with area constraints in the surrounding, in amperage creep [4]. Vogelsang et al. showed the potential of smelters increasing from 110 to 175 kA in 1997, a smelter running at 185 kA in 2019 and 68 % above the initial current [5].

While an expansion usually leads to an expansion of the carbon plant as well, the incremental changes for a current creep can lead to a higher carbon need without significant changes on the equipment of carbon plants [6-8].

The TRIMET Aluminum SE smelter in Hamburg is located in the harbor part. As part of a capacity increase project both ways were considered. The plant is limited in its dimensions by the expansion of container terminals and a natural reserve on the other side. An expansion with a further potline was not suitable for the smelter. Therefore, further amperage creep was considered.

Hamburg smelter ran at 180 kA at the time, while smelters with similar cell dimensions like AP18 technologies or a comparable smelter originally designed as an improved design from Hamburg were running at well above 200 kA. The next strategic steps were an increase to 185 and then 190 kA to increase production capacity in the smelter by 5 %.

As a first limitation the anode size was identified, which at the time had an anode current density of 0.86 A/cm^2 at 180 kA. An increase to 190 kA would change that to 0.91 $A/cm^{2.}$, a value which would not be accepted.

A project for new anode dimensions was started in December 2013. A trial with anodes purchased in China was conducted from January 2015 over a time of 24 months. Finally, in August 2017, the Hamburg smelter changed the anode format– the length increased from 1480 to 1600 – 1625 mm.

The aim was the reduction of energy consumption and a higher current efficiency in the electrolysis due to the larger surface of the anode [8]. It was also deemed a necessary step for further current creep in following years by reducing the anode current density from 0.9 to 0.83 A / cm^2 at the time. Additionally, with a higher baked density, a lower anode height was proposed. This would be beneficial for anode covering and therefore, reduction of air burn. As anodes in the Hamburg smelter are spray coated with aluminium, a saving of ~700 tons aluminium per annum was proposed by elimination of the spray coating, increasing the output of the smelter directly. The target anode height was reduced from 680 to 620 mm, keeping a similar final weight.

2. Planning and Simulation

In order to find proper dimensions for the new anode, measurements were conducted to find the available space in the center channel and the outer channels. It was found, that with the existing retrofit point feeder, a minimal center channel width would be 140 mm (originally 200 mm). This allowed for an increase in length of 30 mm per anode in the center channel. A further reduction would have needed a change for a new feeding system, deemed not financially viable. The main increase of the anode length would have to be towards the side channel, which allowed for an increase of 121 mm until reaching the outer line of the cathode block.

The dimensions of the anodes changed as shown in the following Table 1. The length of 1650 mm can be produced today, however, was never really considered due to its extensive overhang of the cathode.

Table 1. Extension of anodes from original design.

Anode length	Extension side channel	Extension center channel	Out of Cathode shadow
1600 mm	101 mm	19 mm	0 mm
1625 mm	126 mm	19 mm	15 mm
1650 mm	151 mm	19 mm	40 mm

For the reference and new anode dimensions, a thermo-electric model was used to evaluate the heat balance and the ledge formation. The currents used for the evaluation were 180, 182, 185 and 190 kA at the same ACD, which was assumed for the base case. 182 kA is the limitation for the n-1 rectifier operation, with 5 rectifiers running maximum at 47.5 kA.

The models showed that the expected voltage for the larger anodes would be lower than for the base case at 180 kA. None of the models however worked for a current of 180 kA – the anode would touch the calculated ledge. A final model with an increased cover thickness increasing from 6 to 10 cm would allow for operation of the 1600 mm anode at 180 kA.

2.1 Testing Phase

In order to evaluate the maximum dimensions of the anodes, a test with a wooden extension of normal anodes was conducted. This test was conducted in electrolysis cells (see Figure 1 Right) and the rodding shop. It was found that the eventual anode size could not be used during electrical preheating, as the anode would be sitting in or on the ramming paste on the side. Special startup anodes would be required for the future. This enabled a bigger asymmetry and an increase in anode length for all “in operation” anodes. The required second anode length would be supplied by the sister plant in Voerde.

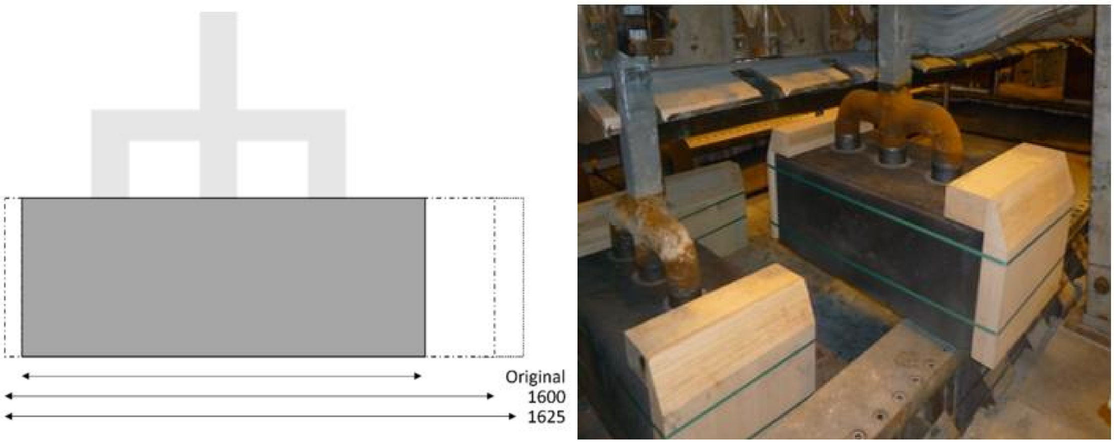

Figure 1. Left: schematic drawing of original and proposed anode formats; not to scale. Right: dummy anode with wooden panels for fitment test in electrolysis cell and rodding shop.

In January 2015, tests in a nine-cell booster section started with Chinese anodes at a length of 1600 mm at 185 kA. The current efficiency was increased significantly. However, in retrospect, the results have to be corrected. The section was never used for metal transfer for new cells, no mother cells and no metal for aluminum coating was taken out. It was expected to gain 0.5 % CE, 30 mV savings in the cell voltage and the non-spraying of anodes would free up to 500 t per year more metal to deliver to the casthouse. The results from the first test batches were excellent, so the decision to implement the project was green lit and the changes in the carbon plant were started.

3. Construction Changes within the Project

Bouche et al. shows many of the common points, which need changes in the carbon plant, if the anode design changes significantly [9]. For Hamburg, the following points had to be changed for the bigger anode:

Green plant
- New vibrocompactor, mould and cover weight
- New anode cooling system

Baking furnace
- Conveying belt system

Rodding shop
- Conveying belt system
- Casting station
- Butt cleaner shot blaster
- Free wagon system
- Anode trays

Electrolysis:
- Spike cutter

While many of the changes could be done during normal operation, both the vibrocompactor and green anode cooling system had to be done during a planned green plant shutdown. In order to cool down green anodes after forming, usually water is sprayed on the surface of the anode or the anode is submerged in a cooling pool. For the system in Hamburg, a world first air-based cooling system was used [10]. This eliminated the need for water treatment due to infiltration of PHCs into the water from the anode and enabled to build a higher storage rack. The high storage rack was installed in 2016, a year prior to the vibrocompactor replacement.

4. Necessary Changes not Identified or Communicated Enough in Planning Phase

Due to the changes in anode dimensions, room for a top layer of anodes for the Essen plant, which are partially produced in Hamburg, was no longer available. This would reduce the overall output of the baking furnace by 3 Essen anodes per pit of Hamburg anodes, with the same weight of Hamburg anodes. This meant a capacity loss for Essen of 12000 anodes and overall reduction of production capacity of ~5%. This necessitated an increase of buying capacity of anodes on the market, as the baking furnace was not able to increase the capacity by that amount.

The anode rota in the electrolysis had to be reduced significantly. However, as soon as that was translated into working schedules, the amount of anode changes per shift increased per team from 9 to 15 and alternating skip days. This model was tested during the first months and was not deemed sustainable, especially during hot outdoor temperatures. In order to reduce the number of anode changes, the target height and weight were increased. However, this change had to be reversed after the allowed loading capacity of the free wagon system in the rodding shop was reduced due to its age. The targeted weight was no longer allowed until the refit of the system was in place, which took until July 2020.

Before the changes were enabled, the plant experienced periods with increased anode cracking on several occasions. These cracking periods ended mostly without any changes in the process settings, hence a real cause was not found and tackled.

The design of the anode would lead to an increased asymmetry. With the design of the anode yoke and relative stub position in the anode, the asymmetry and therefore the current flow in the anode would lead to a higher sensitivity for anode cracking.

5. Operational Issues during and after the Rollout of New Anode Size in the Carbon Plant

Soon after the production start with the new vibrocompactor, the number of anodes with cracks in green anodes and in baked anodes increased. The number of anode rejects increased from below 50 per month in July and August 2017 to more than ten times that amount - a number deemed unsustainable and economically hurtful.

From the beginning, not all cells were using the new dimensions. At first, Line 1 with 180 cells was using the new dimensions. Line 2 with 90 cells was still using old Hamburg stocks, after that changed to Voerde produced old dimensions and then to Chinese produced old dimensions.

Figure 2 shows the scrap for produced anodes for the Hamburg smelter, both green and baked. Several attempts to reduce the critical scrap ratios were made, until it was necessary to use the anodes which were scrapped previously in order to keep the potroom running.

Anodes with the following criteria for scrapping were tested:

- Cracks on the top shaping part between the stub holes
- Horizontal cracks no longer than 10 cm

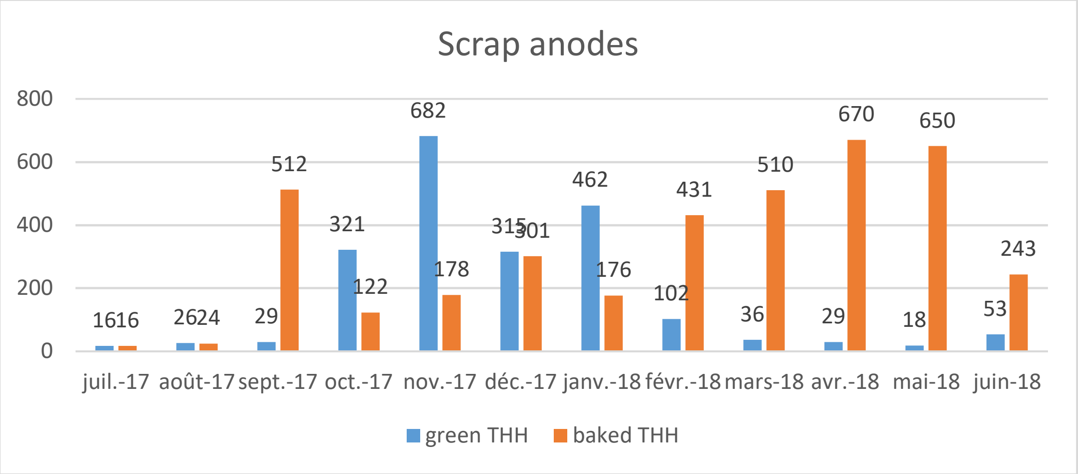

Figure 2. Amount of green and baked scrap from Hamburg produced anodes (includes scrap due to transport as well as production/ process scrap).

Many of the anodes with cracks on the top shaping did not show a higher amount of broken or cracked anodes than those without any visual indications. An R&D Carbon study from that time gave similar indications and did not show a relevant combination of outside and inside cracks [11, 12].

This allowed for more anodes to be used in the cells, as the anode stock without any visual cracks was getting smaller and smaller. The anodes were set in specific sections in the potline, which allowed a better monitoring of the anode quality. Both the batch and crack identifier were written on the anode stems. The production batch sizes were reduced to have only 7 days of operation time with the same batch number.

For some tests, no more slotting of anodes was conducted in order to reduce the instability created by the slots. This however was abandoned fast, as it created no less slabbing.

Table 2. Challenges and problems in green production of anodes.

Underlying, unsolved issues		**New problems from process changes**
Coke	Pitch	-Vacuum as new technology -Changes anode dimensions -Changed anode cooling
Blaine variation	Inconsistent pitch addition	
+/- 450 within 30 minutes	+/- 1 % pitch	

5.1 Pitch Variation

Over several months, different problems with the correct setting of pitch for the anode formulation were occurring. In September 2017, it was noticed, that the volume stream of pitch did stop from time to time due to a pressure buildup in the pitch weighing system. Due to this pressure change and the design of the tubing, pitch foamed and changed its density dramatically. Froth buildup due to insufficient depressurizing led to massive variations in pitch dosing - 30 % of anodes had the proper levels, 35 % were underpitched, 35 % were overpitched.

Afterwards, the self-regulation of the system showed changes in the feed rate corresponding to 8.8 to 15.3 % pitch. This was visual in the baking furnace with both anode packages sticking to each other (from insufficient gasification of volatiles in the pitch) and airburn on the anodes. The change from gravimetric to volumetric pitch addition was decided in October 2017. The density in the anodes changed significantly due to the fluctuation shown in Figure 3. After the decision to use the volumetric control, the density fluctuation was reduced.

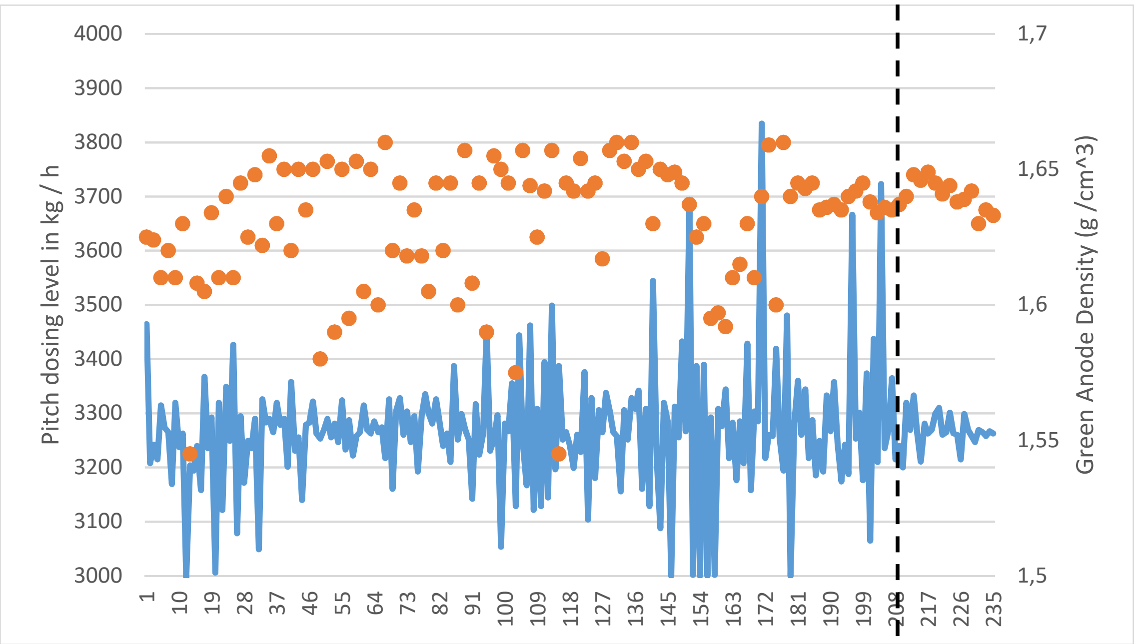

Figure 3. Green Anode density (orange dots) and pitch dosing level (blue line) showed high variations until the decision was taken to set the pitch dosing on a volumetric and not scale-based system (black line). The change of dosing logic immediately had an impact on the green anode density variation.

At the end of 2017, a Coreolis system was installed to first verify and then replace the used weighting system. In April 2018, a drift in the old system was noticed. The target value was at 2600 kg/h, the actual was at 2350 kg/h. The old system showed a value of 2350 +/- 150 kg, while the new reference system showed 2400 ± 25 kg. As the system was only working on the volumetric control and not the gravimetric control, there was no system adapting the values due to raw material changes.

While the pitch dosing already had some difficulties, the variability in Blaine values increased the problems. The value of the ultrafines was measured every 30 minutes and showed a variation of 900 within 2 hours, corresponding to a change in pitch demand of about 1 %. With an increase of Blaine measurements and consequent adaptation of the milling power, the Blaine value variation could be reduced. The decision to install a continuous Blaine measuring system was agreed on and installed during the next two years.

5.2 Over Compaction

With the difficulties in the dosing of pitch and fines, it was hard to reach the target green density of 1.65 consistently. The new target density, up from 1.63, was decided on due to information from a plant in the Middle East, which had reached these values with their raw materials. In order to reach the density, vacuum was used, and the mixer and vibro-compactor were operating at their limits in pressure and power. The cycle time, usually adapted according to the weight and height reached, was always at the maximum allowed time.

The number of cracked anodes was increasing over time. This was true both for green and baked anodes. At times, the scrap ratio in the green plant was reaching ~ 30 %, especially on days with many stops in the green mill. The data from supervision revealed with the indications of different cracks up to 37 % of anodes showing cracks.

As cracking started, first the power of the mixer and vibro-compactor were reduced, also the vacuum was reduced. It was eventually determined that the mixing power was too low, anodes were not homogeneous and this led to cracking within the anodes

5.3 Problems in Potroom: Work Scheduling and Thermo-Chemical System

Due to the stockage being produced before the shutdown of the green plant having inferior reactivity values due to insufficient baking levels (shorter fire cycle time necessary), many cells had developed high carbon dust values. Carbon dusting and airburn were high, which can be assumed from the C% in anode cover material (ACM) [13]. The number of hot pots (T >980 °C, 1000 °C and 1050 °C), as indicated in Figure 4, shows the effect of the anode quality, while the increase in carbon content in secondary alumina (Figure 5 left) and anode cover material (Figure 5 right) shows the influence of carbon dusting.

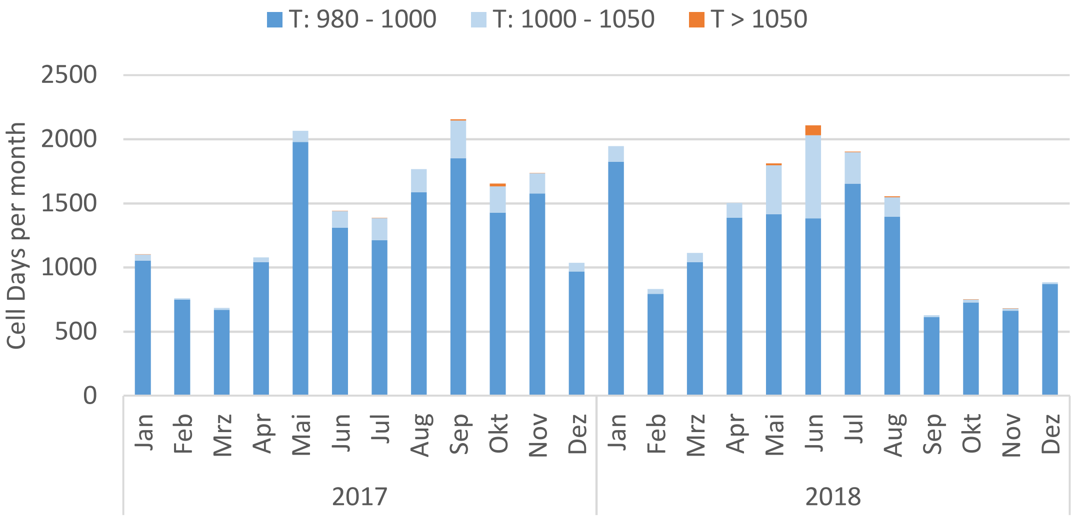

Figure 4. Number of cell days measured with temperature of above 980 °C (blue), 1000 °C (light blue) and 1050 °C (orange). The highest number of cell days with a temperature of 1050 °C and above was recorded in June 2018, with 77 cell days.

With the promise of new anodes, their use in potroom 1 started on August 2nd, 2017. It was highly anticipated, as the problems with the stocked anodes were increasing and potroom performance was deteriorating. The anodes were used without spray coating and the potroom management staff checked every anode over the first days. After the first rota was finished by end of August, it was noticed that the resulting butts were extremely thin and the iron content was increasing.

For the change in anode format, the working schedule had to be changed from 9 anodes per shift per team to 15 anodes, as the new anode rota was reduced from 30 to 27 days. This was to accommodate for the lower usable weight of the anode. By increasing the length of the anode, the butt would become heavier, if not reduced in height. The reduction of butt height was tested, however, with the anode quality issues and bath fluctuations due to inconsistent cover material, the iron content of the metal was increased and the target butt height as well. This meant, the former butt weight of 220 kg/anode was no longer reachable but was closer to 300 kg. Additionally, the maximum anode weight had to be reduced as soon as structural damage on the free-wagon system in the rodding shop was suspected.

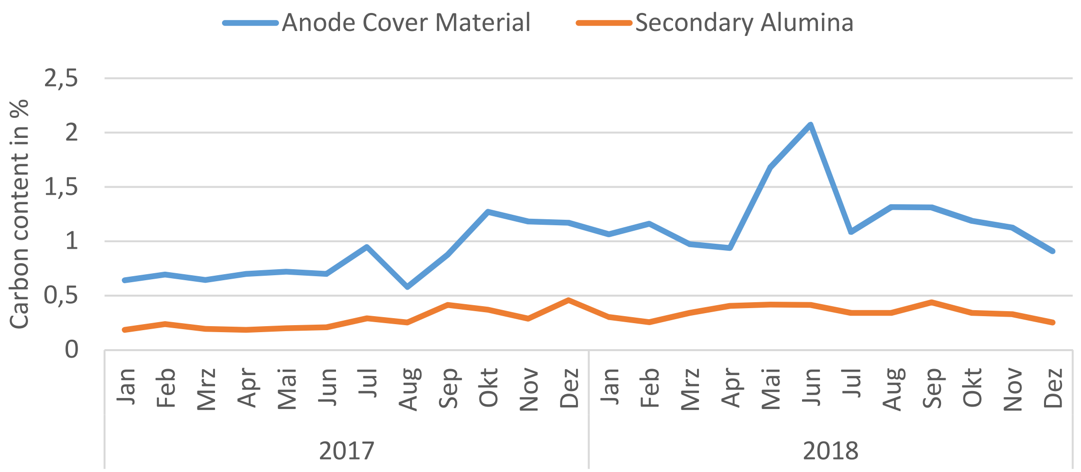

Figure 5. Carbon content in secondary alumina increasing in times with lacking anode quality. Carbon content in anode cover material, carbon is increasing in times of carbon dusting [13].

Due to many spikes and breaking anodes, the target current was reduced. However, as the feeding was set independent of the current a few years before in order to accommodate current changes, the feeding was continuing at the rate of the higher current. This led to many cells with spikes due to sludge formation, leading into a vicious cycle of spiking and cracking anodes. Figure 8 shows the results of the anode issues approximately one year after the anode dimension change. Additionally, a structural problem with the AlF_3 calculation was noticed leading to high AlF_3 addition with cells at temperatures of 1000 °C and higher. Some cells were at 1020 °C and 11% AlF_3, unable to take up any alumina fed to the cell – leading to more sludge spikes again on these cells.

While the anode quality and cracking issues were coming and going in the carbon plant, the electrolysis was having daily issues with cells going above 1000 °C with the anode quality and thermo-chemical system. After 6 months, a decision was taken to measure every anode once a day as soon as the cell was reaching a temperature of 975 °C, which is 12 °C above the target cell temperature. If any of the anodes was suspected to have a spike or burnoff, the anode was written down for an anode inspection. The number of anode inspections was going up massively with up to 10 anodes extra per crane team, which was not sustainable. In June 2018, the backlog of anodes was reaching approximately 350 anodes, which was 2 days' worth of scheduled anode changes. Figure 6 shows a cell in May 2018, which was still operated and taken back to temperatures below 975 °C with incredible work input from the operators. It still failed three weeks later at 1120 °C. A triage decision was taken to switch off 10 of the worst cells out of operation within 24 h to reduce the work on critical cells. These cells sometimes had 3 to 4 burnoff anodes next to each other and were unsafe to operate. Over the span of 6 months of continuing issues, 33 cells were taken out of operation in order to ensure safe operations for the residual 235 cells. Many of the cells were set to be restarted, with some failing immediately due to the damage caused by temperatures at 1050 °C and more.

Figure 6. Cell with extreme dust and excess carbon consumption: Cell 124, 31 May 2018, bath temperature 1072 °C; had to be shut down on 21 June 21 2018 at 1120 °C.

The use of the daily measurements of anodes however allowed to find spikes at a very early stage in the anode life. Figure 7 shows the distribution of anodic incidents relative to the anode change. Many incidents were found within the first 7 days after anode change.

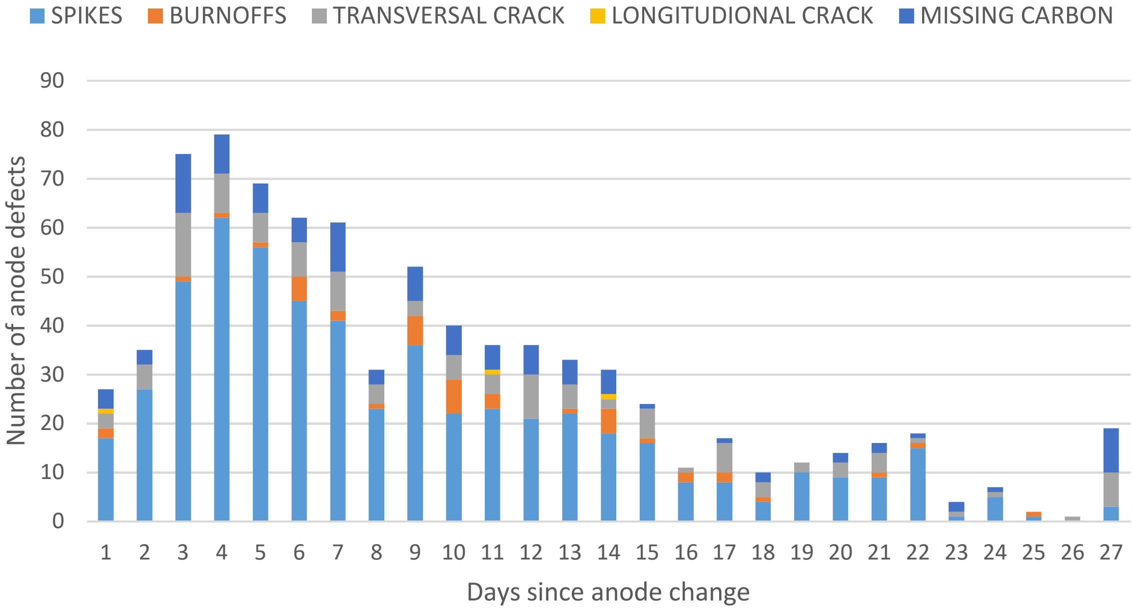

Figure 7. Anode failure mode over 27 days anode rota. The data set includes all anode changes during the last 30 days, which have been marked as defective (example for date: 2018-07-23). There is an increase in anode defects found with the peak on day four, which tapers off.

5.4 Anode Asymmetry and Yoke Design

With the spatial limitations of the anode enlargement, the asymmetry of the stubs in the anode was increased further. As many cracks occurred in the middle of the anode, which was in between two stub holes (see Figure 1 Left), the yoke located to the outer side of the cell was drawing more current. With the help of KAN-NAK, who simulated the anode and yoke assembly, the following current distributions were found.

Table 2. Relative current distribution (%) in stubs both measured and calculated.

Anode length	**Side Channel Stub**	**Middle Stub**	**Center Channel Stub**
1485 [Simulation]	35	32	33
1625 [Simulation]	36	32	32
1625 [Measured]	35	37	28

Observations showed that cast iron would start to melt in some of the stub holes if the anode was cracked. This led to the assumption that the outer stub would draw as much as 50 % of the anode current in case of a crack.

A comparison of the anode pressure caused by heat up and expansion of the yoke showed that the Hamburg yoke was creating 5 times more pressure in the anode than the yoke design used at Essen. This led to tests with shallow stub holes in the hope this would reduce the pressure of cracking. However, the results were inconclusive.

6. Conclusion

Two dates have had an impact on me as a young process engineer. On 13 December 2017, we had 5 green anodes left, that could be used in the baking furnace. Everything else was scrap. On 12 June 2018, we had 15 cells with bath temperature above 1000 °C. The decision was taken to shut down 10 cells that day in order to save the remaining ones.

These experiences showed, that the changes related to anode dimensions can have severe effects down the process chain. It also shows the need for good process monitoring and process engineering. Since the end of 2018, a process engineer has been included in the carbon plant management to monitor the different parameters. Previously, there was no dedicated process engineer working in the carbon plant. Today, with the increased level of process monitoring, we are better prepared to respond to changes in raw material quality.

The issues in the processes in both carbon and electrolysis showed the power of an interorganizational exchange. With the help of colleagues from the plants in Voerde, Essen and Saint-Jean-de-Maurienne, several changes were implemented for the good.

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